(2)

US Army Corps of Engineers

MISCELLANEOUS PAPER EL-88-17

DYE TRACER STUDY AT THE SAGINAW BAY, MICHIGAN, CONFINED DISPOSAL FACILITY

by

Paul R. Schroeder

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

and

Bruce M. McEnroe

University of Kansas
Lawrence, Kansas 66045

December 1988
Final Report

Prepared for US Army Engineer District, Detroit
Detroit, Michigan 48231-1027

Destroy this report when no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Miscellaneous Paper EL-88-17	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION See reverse. / 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) See reverse.	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAED, Detroit / 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Detroit, MI 48231-1027	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Dye Tracer Study at the Saginaw Bay, Michigan, Confined Disposal Facility

12. PERSONAL AUTHOR(S)
Schroeder, Paul R.; McEnroe, Bruce M.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM _____ TO _____	December 1988	32

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	Disposal	Dye tracer
			Dredged material	Seepage

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A dye tracer study was performed in August 1987 at the Saginaw Bay, Michigan, dredged material confined disposal facility (CDF). The purpose of the study was to locate the points or areas of outflow or seepage through prepared limestone dikes of the CDF under a variety of wind conditions. The study was conducted for the US Army Engineer District, Detroit, as part of a larger study performed by the District and the US Environmental Protection Agency to determine whether significant quantities of contaminants were escaping from the site in the seepage through the dikes.

The fluorescent dye Rhodamine WT was added to the water in the CDF and allowed to disperse by wind currents. Water samples were collected every 50 ft (15 m) inside and outside the dikes, and the dye concentrations were measured. Using a mass balance technique,

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 *Previous editions are obsolete.*

6a. NAME OF PERFORMING ORGANIZATION (Continued).

USAEWES, Environmental Laboratory;
University of Kansas

6c. ADDRESS (Continued).

PO Box 631, Vicksburg, MS 39181-0631;
Lawrence, KS 66045

19. ABSTRACT (Continued).

the relative outflow for each 50-ft reach of dike was estimated. Higher seepage rates were determined to exist along the shoreward dike in the deep east side of the south cell of the CDF under all wind conditions.

PREFACE

This report was prepared by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), in fulfillment of reimbursable order number GC NCE-IA-87-0092. The Principal Investigator for this study was Dr. Paul R. Schroeder of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL. The field work was performed during August 1987 by Drs. Schroeder and Robert N. Havis of the WREG; Messrs. Mark Zappi and Sidney Ragsdale of the Water Supply and Wastewater Treatment Group, EED, EL; and Mses. Pam Bedore and Carla Fisher of the Detroit District.

The report was written and prepared by Dr. Schroeder of the WREG and Dr. Bruce M. McEnroe of the University of Kansas. Technical reviewers were Dr. F. Douglas Shields of the WREG and Dr. Michael R. Palermo of the EED. The work was accomplished under the direct supervision of Dr. Schroeder, former Acting Chief, WREG, and Dr. John J. Ingram, Chief, WREG, and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison, Chief, EL. Commander and Director of WES was COL Dwayne G. Lee, EN. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

Schroeder, Paul R., and McEnroe, Bruce M. 1988. "Dye Tracer Study at the Saginaw Bay, Michigan, Confined Disposal Facility," Miscellaneous Paper EL-88-17, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

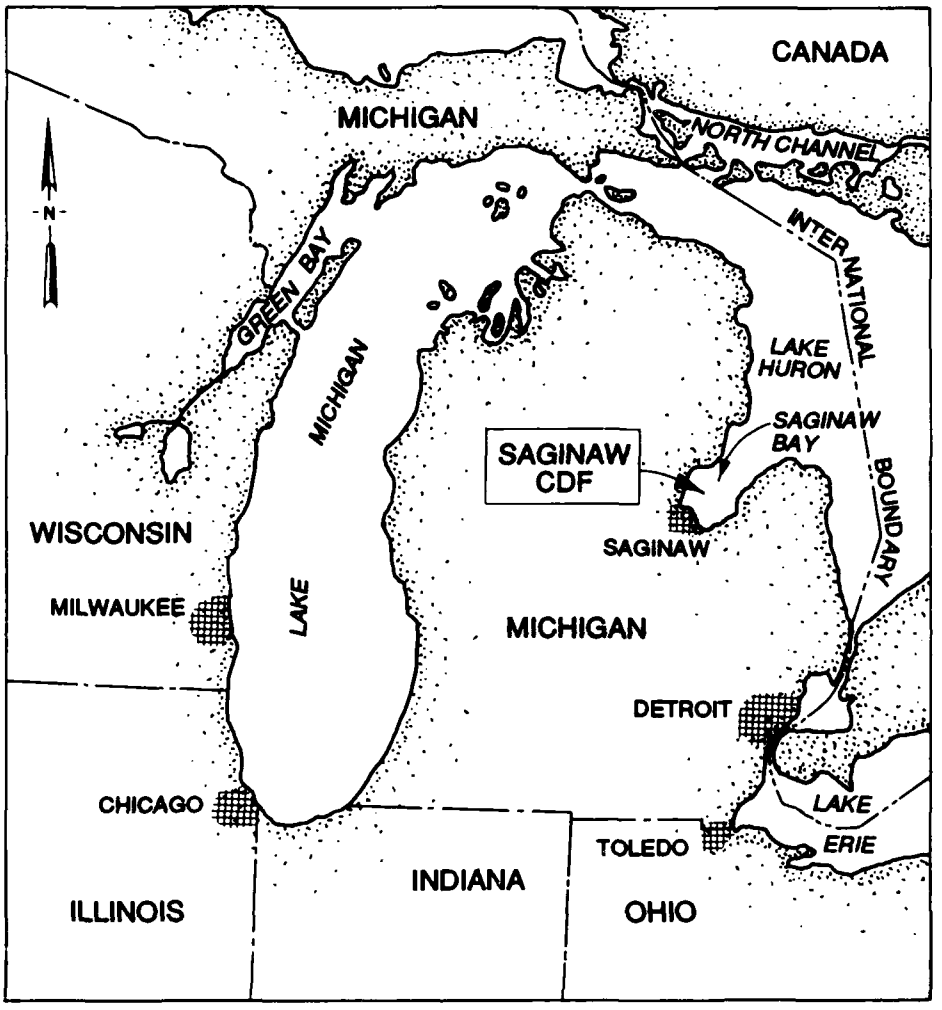
DYE TRACER STUDY AT THE SAGINAW BAY, MICHIGAN, CONFINED DISPOSAL FACILITY

PART I: INTRODUCTION

Background

The Saginaw Confined Disposal Facility (CDF) was designed and built by the U.S. Army Engineer District, Detroit, between 1976 and 1978 to contain material dredged from the Saginaw River entrance channel in Saginaw Bay near Bay City, Michigan. Figure 1 shows the general location of the Saginaw CDF, and Figure 2 shows a plan view of the facility. The facility has been used for disposal of polluted sediments since construction was completed. At the time of this study the north cell was completely filled and the west half of the south cell was nearly filled. About one third of this west half near the dredge pumpout was filled above the water line and the remaining area had less than 3 feet of ponding, most being 1 to 2 feet in depth. The east half of the south cell was nearly empty and water ponded to a depth of about 11 feet.

An Interagency Work Group is evaluating the effectiveness of Great Lakes confined disposal facilities (CDFs) for retaining contaminants from polluted sediments. Representatives from the North Central Division (NCD) of the US Army Corps of Engineers, Region V of the US Environmental Protection Agency (EPA), and Regions III and V of the US Fish and Wildlife Service (FWS) are participating in this group. In September 1987 the EPA performed a biomonitoring study at the Saginaw CDF. It was necessary that biomonitoring be conducted at locations of relatively high seepage through the dikes. The dye tracer study was performed prior to the biomonitoring study to identify these locations. The US Army Engineer District, Detroit, requested the Environmental



VICINITY MAP

SCALE

30 0 30 60 MI

Figure 1. Vicinity map for Saginaw CDF

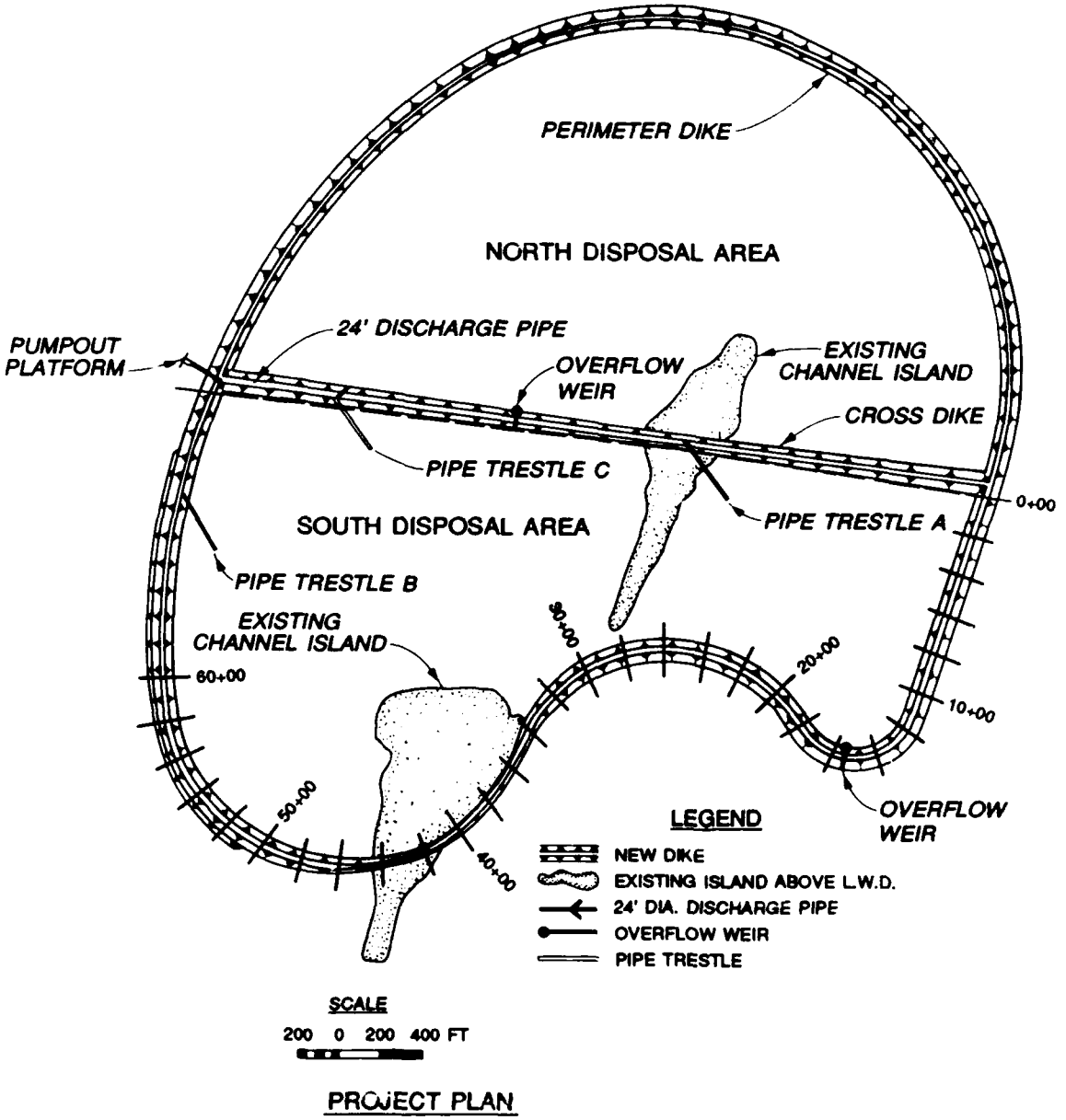


Figure 2. Saginaw confined disposal facility

Engineering Division (EED), US Army Engineer Waterways Experiment Station (WES) to conduct the dye tracer study. This report describes the site and the operational conditions during the study, explains the techniques used, and presents and discusses the results.

Objectives and Approach

The objective of the study was to identify locations or regions along the perimeter dike of the south disposal cell where the seepage rate was significantly above average. Biomonitoring studies were to be focused at these locations. Only relative discharges were of interest; no attempt was made to determine absolute discharges.

The field study was conducted over the period August 10-22, 1987. Intracid Rhodamine WT, a fluorescent dye frequently used in tracer studies, was added to the water in the south disposal cell of the CDF and allowed to disperse throughout the cell. Three sets of water samples were then collected at points inside and outside the perimeter dike. In a preliminary sampling run, samples were collected at 500-ft intervals. In two subsequent detailed sampling runs, samples were collected at 50-ft intervals. Seepage through the dike was driven by a low rate of inflow from the dredge pumpout and by wind set-up. Wind conditions for the three sampling runs differed greatly.

The fluorescence levels of the water samples were measured in a field laboratory using a Turner Model 10 fluorometer. Fluorescence units were converted to dye concentrations using field-generated calibration curves that accounted for background fluorescence inside and outside the CDF. The background water samples used in calibration were collected outside the CDF at the mouth of the Saginaw River and inside the CDF before the dye was added.

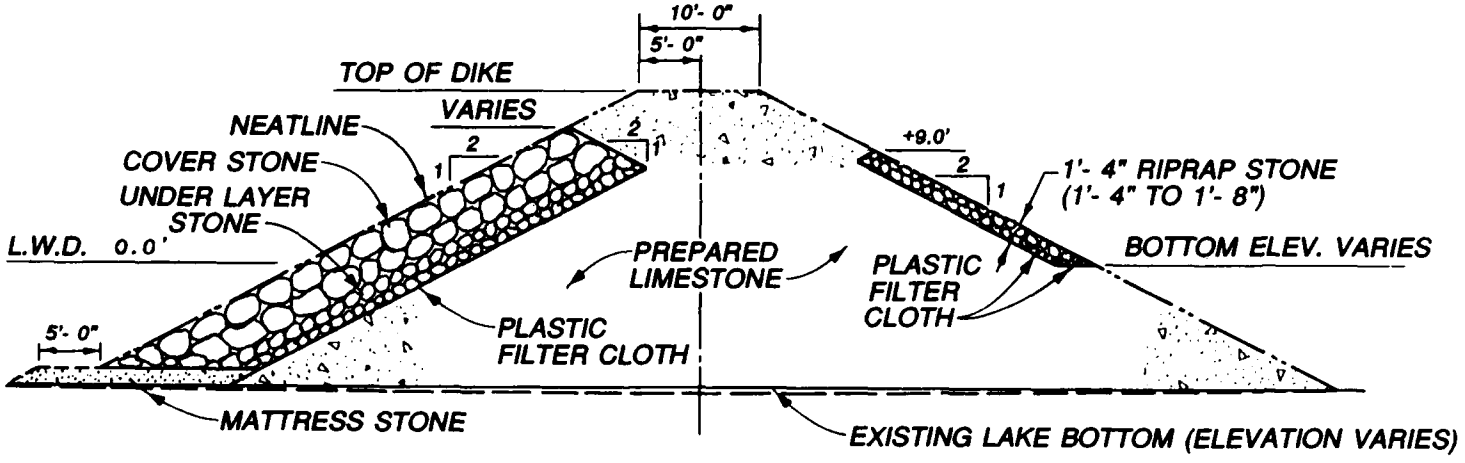
Relative discharges through the dike were estimated from dye concentrations inside and outside the dike using an analysis based on conservation of mass. The equations used in this analysis are derived in Appendix A. The local seepage rate at each sample point is expressed as a fraction of the average seepage rate over the entire sampling region.

PART II: DYE TRACER STUDY

Site Description

The Saginaw Confined Disposal Facility (CDF) is a diked area adjacent to the Saginaw River entrance channel in Saginaw Bay near Bay City, Michigan. Figure 2 shows a plan view of the facility with station numbering along the south perimeter dike. The perimeter dike is approximately 13,900 ft long and encloses an area of approximately 280 acres. A 3800-ft-long cross dike divides the CDF into north and south disposal cells of nearly equal size. A typical cross-section of the dikes is shown in Figure 3. The perimeter dikes have a prepared limestone core which was designed to be permeable and act as a filter for the discharge. An overflow weir located along the perimeter dike allows direct discharge from the south cell of the CDF into Saginaw Bay. The weir was designed to handle discharge from the CDF when and if the dikes become clogged. The weir was not used during this disposal operation. The dredge pumpout is located on the west side of the CDF adjacent to the west intersection of the perimeter dike and cross dike. Three discharge points may be used in the south cell to spread the material throughout the site; only the two points in the northwest corner of the south cell were used during this project.

The dye tracer study was concerned with seepage through the perimeter dike of the south cell of the CDF. The south cell has approximately an area of 140 acres and a perimeter of 10,500 ft (7700 ft of perimeter dike and 3800 ft of cross dike). Parts of two islands that existed prior to construction of the CDF are enclosed within the CDF. The ponded water in the south cell is considerably deeper on the east side of the central island than on the



TYPICAL DIKE DETAIL

Figure 3. Typical cross section of Saginaw CDF dikes

west side of this island. A delta of dredged material had formed along the west side of the south cell from station number 56+00 to the cross dike.

Site Activities Summary

Field work began on 10 August 1987. After collecting background water samples from the CDF, 175 pounds of liquid Intracid Rhodamine WT fluorescent dye were added to the south cell (125 pounds in the deeper east side and 50 pounds in the shallower west side). A 3500-ft-long line of dye was poured from a boat parallel to the cross dike about 100 ft to the south. A light wind from the NNE dispersed the dye across the cell toward the perimeter dike.

On 12 August 1987, sampling locations were marked with paint at 50-ft intervals along the perimeter dike, starting from NE corner of the south cell. Water samples were taken from the CDF at eight locations along the perimeter dike to determine how uniformly the dye was dispersed. The dye concentrations at these locations were similar; therefore, the dye was considered to be well dispersed. Winds were again light (2 to 5 mph) from the NNE. On 13 August 1987, dye standards were prepared, the fluorometers were cleaned and tested, and standard calibration curves were developed. In the afternoon, an additional 75 pounds of dye were added to the CDF (50 pounds in the east side and 25 pounds in the west side) in the same manner as before.

On the afternoon of 14 August 1987, a preliminary sampling run was conducted to determine whether the newly added dye was well dispersed and whether the dye was detectable outside the CDF under the existing conditions of light winds and low inflow (about 5 cfs). Winds were again light (2 to 5 mph) from the NNE. Winds were measured at the Saginaw Area office located about 1 mile from the mouth of the Saginaw River and about 3 miles from the

CDF. Samples were collected on each side of the dike at 500-foot intervals starting 100 feet from the NE corner of the south cell.

On 15 August 1987, a background water sample was collected at the mouth of the Saginaw River just inside Saginaw Bay at Channel Marker 29, about 5000 feet upstream from the CDF. The fluorometers were recalibrated and a new standard curve was generated to better account for background fluorescence outside the CDF.

On 17 August 1987, the first detailed sampling run was conducted. Water samples were collected inside and outside the dike at 50-foot intervals wherever water was ponded along the dike inside the CDF. Winds were moderate to strong (10 to 20 mph) from the WSW, and waves were 1 to 2 feet high. A second detailed sampling run was conducted on 21 August 1987. Samples were again collected at 50-foot intervals. Winds were moderate to strong (15 to 20 mph) from the SSW. The inflow rate was about 8 cfs for first detailed sampling run and about 5 cfs for the second.

Results and Discussion

The locations of the sampling points along the perimeter dike are indicated by distances measured clockwise along the dike, starting at the east intersection of the perimeter dike and the cross dike. These distances are shown in Figure 2 as stations (e.g., Sta. 25+00 denotes a point 2500 ft from the starting point, measured clockwise along the dike). The west intersection of the perimeter dike and the cross dike is at Sta. 77+00; however, a delta of dredged material extended from Sta. 56+00 to Sta. 77+00, so samples were not collected over this reach.

For all three sampling periods, three types of results are presented for each sampling point: (1) dye concentrations inside and outside the dike,

expressed in parts per billion (ppb); (2) the relative discharge, defined as the ratio of the discharge per unit length at the sampling point to the average discharge per unit length between Sta. 0+00 and Sta. 56+00; and (3) the percent discharge, defined as the ratio of the discharge through the reach associated with the sampling point to the total discharge through dike between Sta. 0+00 and Sta. 56+00, expressed as a percentage. The reach associated with a sampling point is bounded by points midway between the sampling point and the adjacent sampling point on each side. For the first and last sampling points, which have only one adjacent sampling point, the associated reaches extend to the boundaries of the sampling region. It is important to note that the relative discharge at a sampling point is independent of the length of its associated reach, while the percent discharge depends directly on the length of this reach. The equations used to estimate relative discharge and percent discharge from dye concentration data are derived in Appendix A.

The preliminary sampling run was conducted on 14 August 1987. Winds were light (2 to 5 mph) from the NNE, toward the reach from Sta. 14+00 ft to Sta. 30+00 and the reach from Sta. 40+00 to Sta. 77+00. The dye concentrations and relative discharges at the sampling points are plotted in Figures 4 and 5 and listed in Table 1. Seepage was found to occur between Sta. 11+00 and Sta. 46+00. Above-average seepage occurred in a downwind reach of deep water between Sta. 21+00 and Sta. 31+00.

The first detailed sampling run was conducted on 17 August 1987. The winds were moderate to strong (10 to 20 mph) from the WSW, toward the reach from Sta. 0+00 to Sta. 15+00 and the reach from Sta. 30+00 to Sta. 45+00. The dye concentrations and relative discharges for this run are presented in Table 2 and plotted in Figures 6 and 7. These results differed somewhat from those of the preliminary run. The highest relative discharge occurred along the

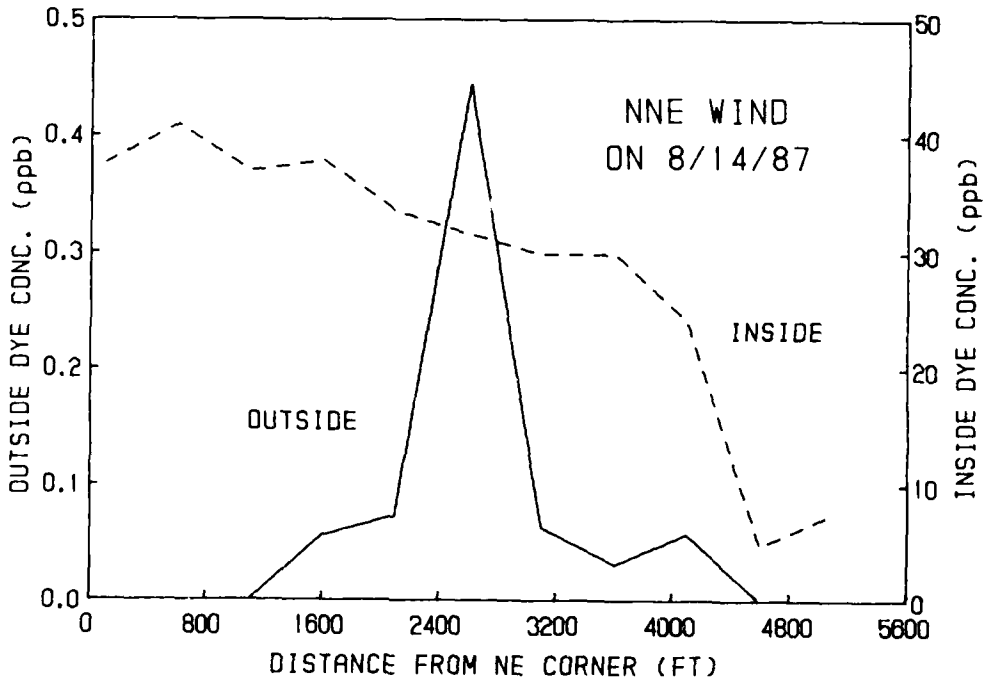


Figure 4. Measured dye concentrations from preliminary sampling run

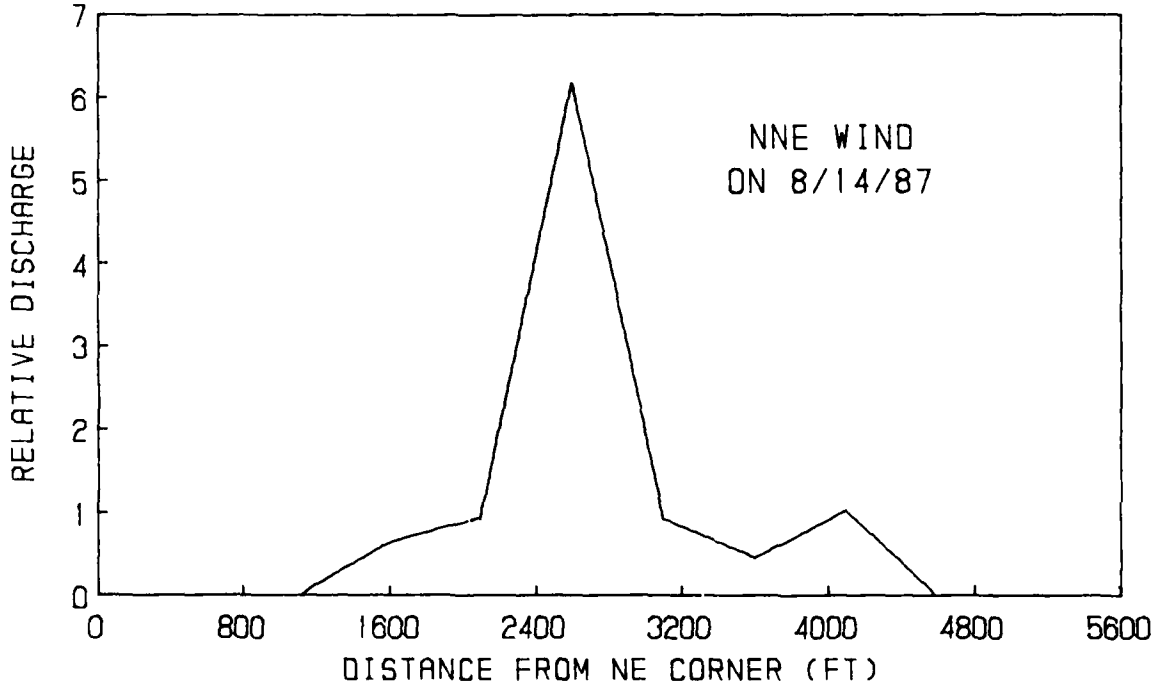


Figure 5. Seepage results from preliminary sampling run

Table 1

Results of the Preliminary Dye Study on 8/14/87

Sample No.	Station	Relative Discharge	Percent Discharge	Conc. Outside (ppb)	Conc. Inside (ppb)
1	1+00	0.00	0.0	0.000	37.5
2	6+00	0.00	0.0	0.000	40.9
3	11+00	0.00	0.0	0.000	36.9
4	16+00	0.65	6.3	0.057	37.9
5	21+00	0.95	9.3	0.073	33.5
6	26+00	6.19	60.7	0.445	31.5
7	31+00	0.93	9.1	0.064	29.9
8	36+00	0.45	4.4	0.031	29.9
9	41+00	1.03	10.1	0.058	24.2
10	46+00	0.00	0.0	0.000	4.7
11	51+00	0.00	0.0	0.000	7.5

curve between the east (downwind) dike and the overflow weir, from Sta. 13+00 to Sta. 15+50. Over the reach from Sta. 13+00 to Sta. 24+00, the discharge per unit length exceeded twice the average value. Above-average seepage occurred from Sta. 13+00 to Sta. 25+00 ft on the deep side of the south cell, and from Sta. 30+00 to Sta. 43+00 ft along a downwind reach on the shallow side. As in the preliminary test, little seepage occurred along the east dike from Sta. 0+00 to Sta. 13+00 despite this reach being downwind. The very shallow reach from Sta. 43+00 to Sta. 56+00 also showed little seepage.

The second detailed sampling run was conducted on 21 August 1987. Winds were moderate to strong (15 to 20 mph) from the SSW, toward the cross dike and away from all reaches of the perimeter dike. The dye concentrations and relative discharges for this sampling run are presented in Table 3 and plotted in Figures 8 and 9. Despite a different wind direction, these results are very similar to those from the first detailed sampling run. Detectable seepage was found to occur from Sta. 10+00 to Sta. 46+00. Above-average seepage occurred from Sta. 13+00 to Sta. 42+00. Between Sta. 15+00 and

Table 2

Results of the Dye Study on 8/17/87

Sample No.	Station	Relative Discharge	Percent Discharge	Conc. Outside (ppb)	Conc. Inside (ppb)
1	1+00	0.11	0.05	0.024	27.1
2	1+50	0.10	0.09	0.024	29.3
3	1+00	0.08	0.07	0.018	27.9
4	1+50	0.13	0.12	0.029	28.3
5	2+00	0.00	0.00	0.000	29.1
6	2+50	0.08	0.07	0.018	29.5
7	3+00	0.10	0.09	0.024	30.3
8	3+50	0.05	0.05	0.012	30.3
9	4+00	0.00	0.00	0.000	31.9
10	4+50	0.12	0.11	0.029	31.9
11	5+00	0.11	0.10	0.029	33.7
12	5+50	0.11	0.10	0.029	34.8
13	6+00	0.11	0.10	0.029	34.0
14	6+50	0.02	0.02	0.007	34.8
15	7+00	0.07	0.06	0.018	33.9
16	7+50	0.07	0.06	0.018	33.5
17	8+00	0.15	0.14	0.029	24.8
18	8+50	0.12	0.11	0.024	23.9
19	9+00	0.04	0.03	0.007	23.9
20	9+50	0.12	0.11	0.024	24.0
21	10+00	0.09	0.09	0.018	23.9
22	10+50	0.12	0.11	0.024	24.8
23	11+00	0.18	0.16	0.035	24.9
24	11+50	0.14	0.13	0.029	25.5
25	12+00	0.20	0.19	0.040	25.1
26	12+50	0.37	0.34	0.074	25.1
27	13+00	2.66	2.42	0.524	25.3
28	13+50	3.10	2.82	0.619	25.8
29	14+00	4.15	3.78	0.799	25.1
30	14+50	4.06	3.70	0.765	24.5
31	15+00	5.61	5.10	1.011	23.8
32	15+50	2.57	2.34	0.467	23.4
33	16+00	2.18	1.98	0.422	24.9
34	16+50	1.68	1.53	0.327	24.9
35	17+00	2.15	1.95	0.411	24.6
36	17+50	2.08	1.89	0.417	25.7
37	18+00	2.02	1.83	0.406	25.8
38	18+50	1.98	1.80	0.394	25.6
39	19+00	2.50	2.27	0.495	25.5
40	19+50	2.83	2.57	0.569	25.9
41	20+00	2.20	2.00	0.451	26.3

(Continued)

(Sheet 1 of 3)

Table 2 (Continued)

Sample No.	Station	Relative Discharge	Percent Discharge	Conc. Outside (ppb)	Conc. Inside (ppb)
42	20+50	1.52	1.38	0.304	25.6
43	21+00	2.09	1.90	0.422	25.9
44	21+50	3.56	3.24	0.709	25.8
45	22+00	2.86	2.60	0.574	25.9
46	22+50	2.48	2.26	0.518	26.8
47	23+00	1.98	1.80	0.400	25.9
48	23+50	3.77	3.43	0.754	25.9
49	24+00	1.56	1.42	0.316	25.8
50	24+50	1.89	1.71	0.383	26.0
51	25+00	0.70	0.63	0.142	25.8
52	25+50	0.95	0.87	0.198	26.4
53	26+00	1.10	1.00	0.226	26.0
54	26+50	1.02	0.93	0.215	26.8
55	27+00	0.44	0.40	0.091	26.0
56	27+50	0.35	0.32	0.074	26.9
57	28+00	0.57	0.52	0.119	26.3
58	28+50	0.69	0.63	0.142	26.0
59	29+00	0.54	0.49	0.108	25.3
60	29+50	0.66	0.60	0.130	24.9
61	30+00	0.87	0.79	0.170	24.9
62	30+50	1.15	1.04	0.226	25.0
63	31+00	1.42	1.29	0.276	24.9
64	31+50	1.46	1.33	0.288	25.1
65	32+00	1.47	1.34	0.282	24.4
66	32+50	1.42	1.29	0.276	24.9
67	33+00	1.63	1.48	0.316	24.8
68	33+50	1.41	1.28	0.276	24.9
69	34+00	1.27	1.15	0.254	25.5
70	34+50	1.26	1.15	0.248	25.1
71	35+00	1.30	1.18	0.254	24.9
72	35+50	1.37	1.24	0.265	24.8
73	36+00	1.28	1.16	0.248	24.7
74	36+50	1.15	1.04	0.226	25.0
75	37+00	1.18	1.07	0.232	25.1
76	37+50	1.15	1.05	0.226	24.9
77	38+00	1.13	1.03	0.220	24.8
78	38+50	0.96	0.88	0.186	24.6
79	39+00	1.24	1.13	0.237	24.3
80	39+50	1.27	1.16	0.248	24.9
81	40+00	1.16	1.05	0.226	24.9
82	40+50	1.18	1.07	0.232	24.9
83	41+00	1.74	1.58	0.338	24.9
84	41+50	2.08	1.89	0.389	24.0

(Continued)

Table 2 (Concluded)

Sample No.	Station	Relative Discharge	Percent Discharge	Conc. Outside (ppb)	Conc. Inside (ppb)
85	42+00	0.75	0.69	0.147	24.8
86	42+50	1.22	1.11	0.220	23.0
87	43+00	1.71	1.55	0.327	24.4
88	43+50	0.15	0.14	0.029	24.8
89	44+00	0.15	0.14	0.029	24.8
90	44+50	0.14	0.13	0.029	25.8
91	45+00	0.04	0.03	0.007	23.1
92	45+50	0.19	0.17	0.035	23.4
93	46+00	0.18	0.17	0.035	23.9
94	46+50	0.16	0.14	0.029	23.5
95	47+00	0.00	0.00	0.000	19.8
96	47+50	0.04	0.03	0.007	23.9
97	48+00	0.01	0.01	0.001	24.1
98	48+50	0.13	0.12	0.024	23.5
99	49+00	0.17	0.15	0.035	25.9
100	49+50	0.00	0.00	0.000	23.1
101	50+00	0.19	0.17	0.035	23.7
102	50+50	0.00	0.00	0.000	23.6
103	51+00	0.00	0.00	0.000	23.3
104	51+50	0.00	0.00	0.000	23.4
105	52+00	0.00	0.00	0.000	23.9
106	52+50	0.00	0.00	0.000	23.7
107	53+00	0.00	0.00	0.000	21.6
108	53+50	0.00	0.00	0.000	22.6
109	54+00	0.00	0.00	0.000	19.9
110	54+50	0.00	0.00	0.000	24.0
111	55+00	0.00	0.00	0.000	22.8

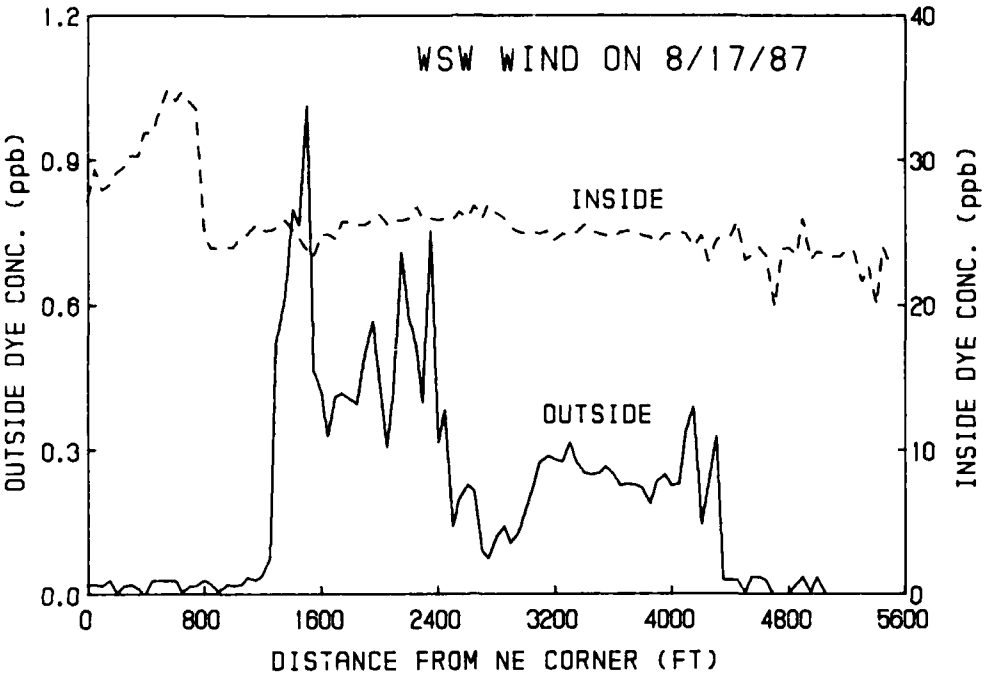


Figure 6. Measured dye concentrations from first detailed sampling run

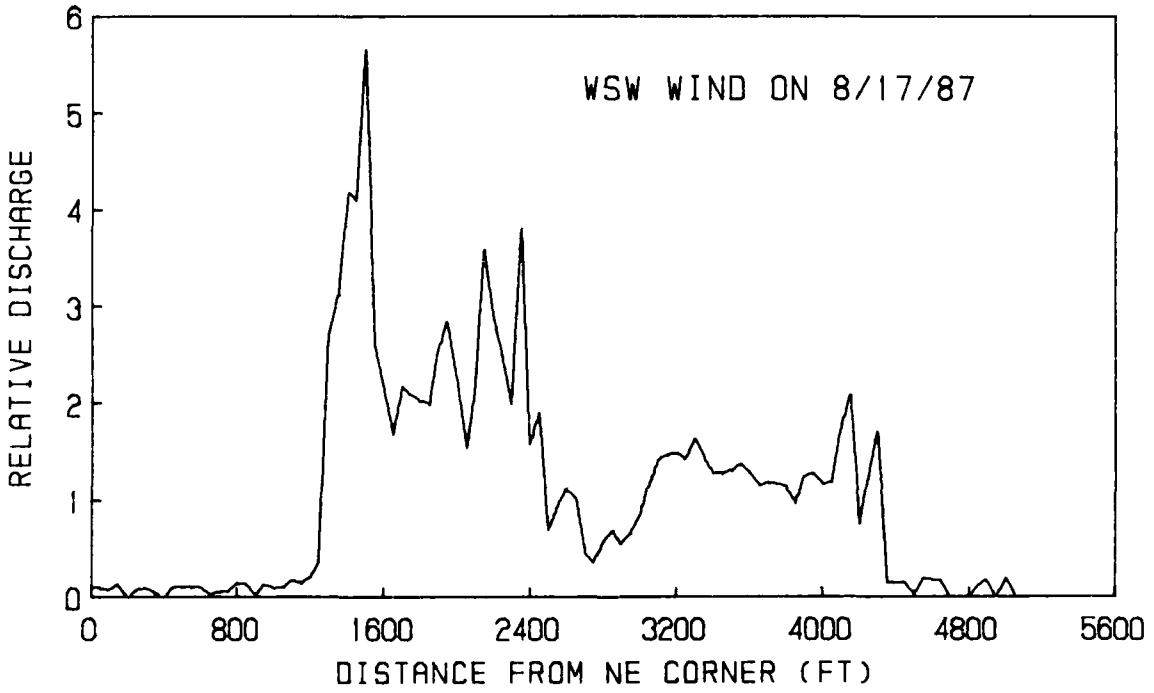


Figure 7. Seepage results from first detailed sampling run

Table 3

Results of the Dye Study on 8/21/87

Sample No.	Station	Relative Discharge	Percent Discharge	Conc. Outside (ppb)	Conc. Inside (ppb)
1	0+00	0.02	0.01	0.012	24.4
2	0+50	0.14	0.13	0.085	26.0
3	1+00	0.02	0.02	0.012	25.1
4	1+50	0.06	0.05	0.035	25.4
5	2+00	0.05	0.04	0.029	26.0
6	2+50	0.05	0.04	0.029	25.8
7	3+00	0.05	0.05	0.029	25.3
8	3+50	0.10	0.09	0.057	25.7
9	4+00	0.06	0.05	0.035	26.0
10	4+50	0.03	0.03	0.018	25.9
11	5+00	0.11	0.10	0.063	25.7
12	5+50	0.03	0.03	0.018	25.8
13	6+00	0.06	0.05	0.035	25.5
14	6+50	0.03	0.03	0.018	25.0
15	7+00	0.05	0.04	0.029	25.8
16	7+50	0.08	0.07	0.046	25.9
17	8+00	0.04	0.04	0.024	25.5
18	8+50	0.11	0.10	0.069	25.9
19	9+00	0.10	0.09	0.057	25.9
20	9+50	0.13	0.11	0.074	25.5
21	10+00	0.13	0.12	0.080	25.8
22	10+50	0.26	0.23	0.158	26.9
23	11+00	0.34	0.31	0.203	26.1
24	11+50	0.52	0.47	0.316	26.8
25	12+00	0.70	0.64	0.417	26.0
26	12+50	1.11	1.00	0.636	25.5
27	13+00	0.83	0.75	0.490	26.0
28	13+50	1.04	0.95	0.585	24.9
29	14+00	1.46	1.32	0.844	25.9
30	14+50	1.94	1.76	1.103	25.7
31	15+00	2.40	2.18	1.365	25.9
32	15+50	1.85	1.68	1.099	26.8
33	16+00	1.87	1.70	1.108	26.8
34	16+50	2.06	1.87	1.181	25.9
35	17+00	2.19	1.99	1.258	26.1
36	17+50	2.51	2.28	1.404	25.6
37	18+00	2.38	2.16	1.355	26.0
38	18+50	2.38	2.17	1.350	25.9
39	19+00	2.35	2.13	1.326	25.8
40	19+50	2.88	2.62	1.617	25.9
41	20+00	2.27	2.07	1.258	25.2

(Continued)

Table 3 (Continued)

Sample No.	Station	Relative Discharge	Percent Discharge	Conc. Outside (ppb)	Conc. Inside (ppb)
42	20+50	1.86	1.69	1.026	24.9
43	21+00	2.49	2.26	1.365	25.1
44	21+50	3.07	2.79	1.626	24.6
45	22+00	2.69	2.45	1.438	24.5
46	22+50	3.12	2.84	1.675	24.9
47	23+00	1.94	1.77	1.050	24.4
48	23+50	2.84	2.58	1.505	24.4
49	24+00	1.55	1.41	0.855	24.7
50	24+50	2.25	2.04	1.210	24.5
51	25+00	1.48	1.35	0.821	24.8
52	25+50	2.31	2.10	1.249	24.6
53	26+00	1.78	1.62	0.968	24.5
54	26+50	2.40	2.18	1.297	24.7
55	27+00	1.38	1.25	0.765	24.8
56	27+50	1.05	0.96	0.591	24.9
57	28+00	1.30	1.18	0.715	24.5
58	28+50	1.56	1.42	0.844	24.2
59	29+00	1.56	1.42	0.872	25.1
60	29+50	1.46	1.33	0.827	25.3
61	30+00	1.54	1.40	0.855	24.9
62	30+50	1.80	1.64	0.929	23.2
63	31+00	1.14	1.04	0.585	22.8
64	31+50	1.36	1.24	0.664	21.7
65	32+00	1.29	1.17	0.636	21.9
66	32+50	1.47	1.34	0.715	21.7
67	33+00	1.75	1.59	0.844	21.6
68	33+50	1.69	1.54	0.788	20.9
69	34+00	1.43	1.30	0.670	20.9
70	34+50	1.00	0.91	0.473	20.9
71	35+00	1.12	1.01	0.524	20.8
72	35+50	1.51	1.37	0.703	20.9
73	36+00	1.25	1.13	0.585	20.9
74	36+50	0.90	0.82	0.428	20.9
75	37+00	1.66	1.51	0.754	20.4
76	37+50	0.87	0.79	0.366	18.6
77	38+00	1.32	1.20	0.614	20.6
78	38+50	0.89	0.81	0.394	19.4
79	39+00	1.14	1.04	0.524	20.3
80	39+50	1.11	1.01	0.501	20.1
81	40+00	1.32	1.20	0.619	20.9
82	40+50	2.02	1.83	0.958	21.5
83	41+00	0.85	0.77	0.422	21.9
84	41+50	1.73	1.57	0.844	21.9

(Continued)

Table 3 (Concluded)

Sample No.	Station	Relative Discharge	Percent Discharge	Conc. Outside (ppb)	Conc. Inside (ppb)
85	42+00	0.45	0.41	0.226	22.1
86	42+50	0.85	0.77	0.428	22.2
87	43+00	0.61	0.56	0.316	22.6
88	43+50	0.80	0.72	0.400	22.1
89	44+00	0.39	0.36	0.203	22.6
90	44+50	0.06	0.05	0.029	20.9
91	45+00	0.07	0.06	0.035	21.9
92	45+50	0.43	0.39	0.215	21.8
93	46+00	0.42	0.38	0.220	22.9
94	46+50	0.38	0.35	0.186	21.3
95	47+00	0.07	0.06	0.035	21.9
96	47+50	0.16	0.14	0.080	22.0
97	48+00	0.09	0.08	0.046	22.0
98	48+50	0.11	0.10	0.057	21.8
99	49+00	0.08	0.07	0.040	21.4
100	49+50	0.04	0.04	0.018	20.1
101	50+00	0.00	0.00	0.001	22.4
102	50+50	0.00	0.00	0.000	21.4
103	51+00	0.00	0.00	0.000	21.9
104	51+50	0.00	0.00	0.000	21.7
105	52+00	0.00	0.00	0.000	21.6
106	52+50	0.00	0.00	0.000	21.8
107	53+00	0.00	0.00	0.000	21.3
108	53+50	0.00	0.00	0.000	21.3
109	54+00	0.00	0.00	0.000	20.1
110	54+50	0.00	0.00	0.000	15.9
111	55+00	0.00	0.00	0.000	14.7

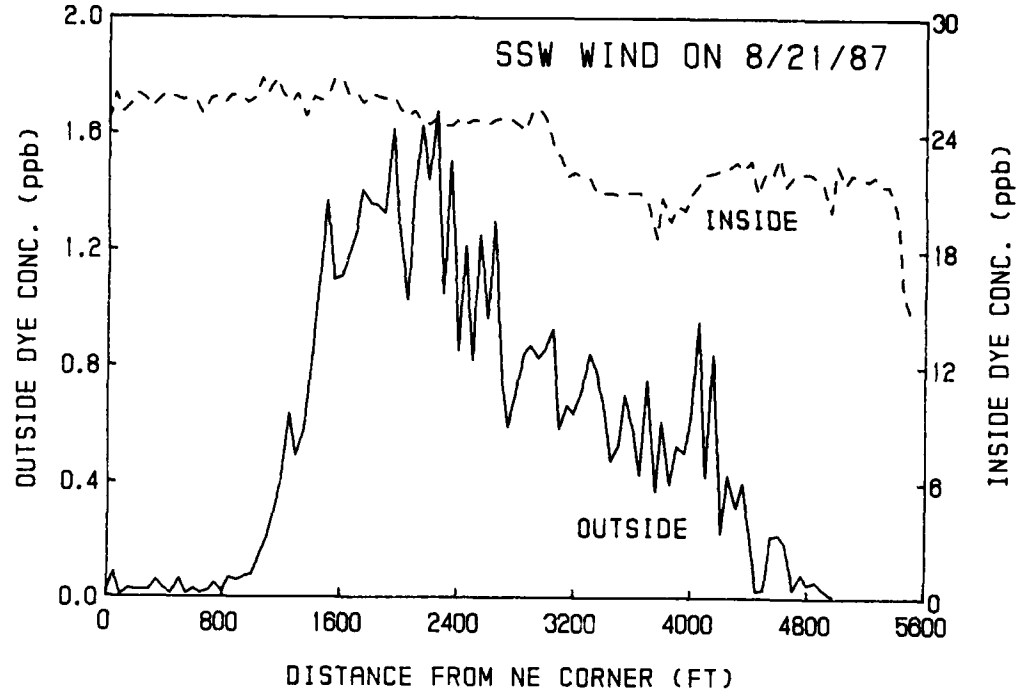


Figure 8. Measured dye concentrations from second detailed sampling run

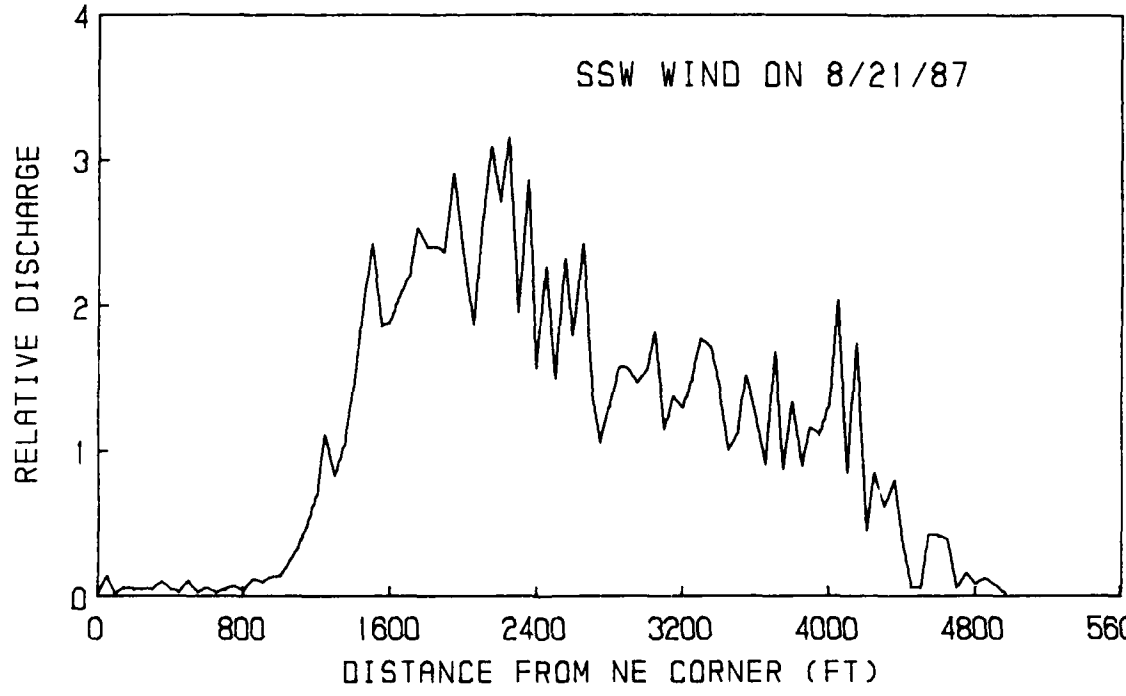


Figure 9. Seepage results from second detailed sampling run

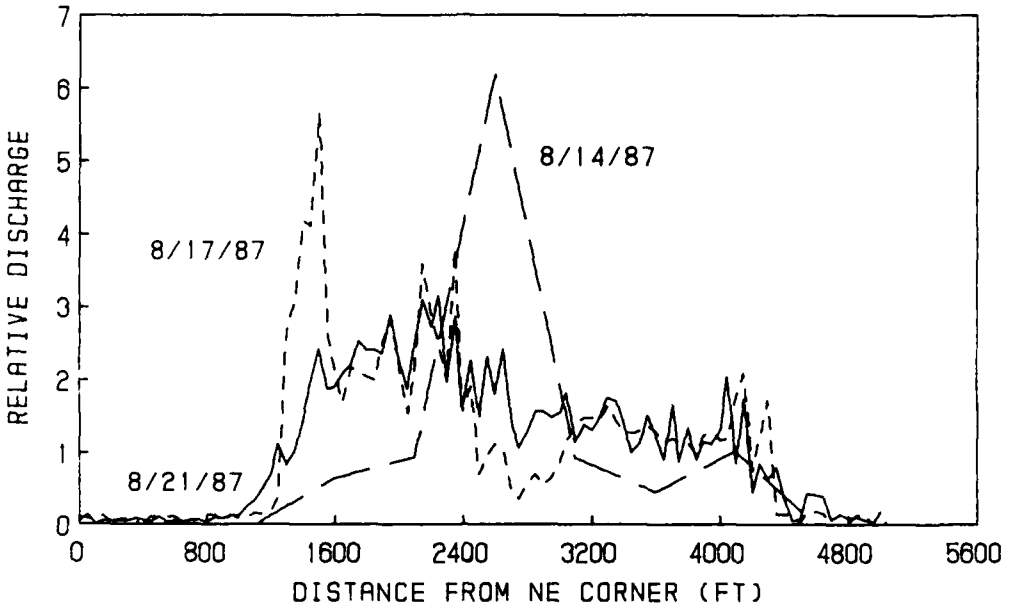


Figure 10. Summary of seepage results from all sampling runs

Sta. 26+00, the discharge per unit length exceeded twice the average value. During this sampling run, the seepage through the perimeter dike was apparently driven by the discharge from the dredge pumpout since seepage occurred primarily from upwind portions of the CDF's perimeter dike.

Figure 10 compares the spatial distributions of relative discharge for the three sampling runs. The locations of seepage were largely independent of the wind direction; however, the quantity of seepage at these locations was somewhat dependent on wind. Despite these differences, the following generalizations can be made: (1) over the reaches from Sta. 0+00 to Sta. 11+00 and from Sta. 46+00 to Sta. 56+00, seepage is relatively insignificant; (2) over the reach from Sta. 13+00 to Sta. 42+00, the discharge per unit length generally exceeds the average discharge per unit length for the entire 5600-ft-long sampling region (i.e., the relative discharge exceeds unity); and (3) over the reach from Sta. 15+00 to Sta. 24+00, the discharge per unit length generally exceeds twice this average value.

PART III: CONCLUSIONS

A dye tracer study was performed at the Saginaw CDF to determine the spatial distribution of relative discharge through the perimeter dike of the south disposal area. Based on the results of three sampling runs, each with a different wind direction, the following conclusions are warranted:

1. Over the reaches from Sta. 0+00 to Sta. 11+00 and from Sta. 46+00 to Sta. 56+00, seepage is relatively insignificant.

2. Over the reach from Sta. 13+00 to Sta. 42+00, the discharge per unit length generally exceeds the average discharge per unit length for the entire 5600-ft-long sampling region for all wind conditions observed.

3. Over the reach from Sta. 15+00 ft to Sta. 24+00 ft, the discharge per unit length generally exceeds twice this average value for all wind conditions observed.

4. The location of seepage was largely independent of the wind direction; although the magnitude of the seepage at some locations varied somewhat with wind direction.

These locations are distances in feet along the perimeter dike from the east intersection of the perimeter dike and the cross dike. The stationing along the perimeter dike is shown in Figure 2.

APPENDIX A: DERIVATION OF FLOW QUANTIFICATION EQUATIONS

A mass balance for the dye flow through a unit length of the containment dike may be represented by the equation

$$q_L * C_{IN} = (q_L + q_{DIL}) * C_{OUT} \quad \text{(A1)}$$

where:

q_L = water discharge through the dike, per unit length

C_{IN} = dye concentration inside containment area

C_{OUT} = dye concentration outside containment area

q_{DIL} = dilution discharge outside containment area, per unit length

Let the ratio C_{OUT}/C_{IN} be termed the concentration ratio and denoted C_R. Rearranging Equation (A1) yields the following equation for q_L:

$$q_L = q_{DIL} * \frac{C_R}{1 - C_R} \quad \text{(A2)}$$

In this analysis, the dilution discharge, q_{DIL}, is the rate of water being mixed with the seepage both during advection and dispersion in the dike and by dispersion at the outside face of the dike. This dilution rate is assumed to be constant along the dike since the wave action and currents do not vary greatly along the dike.

Consider a dike that is divided into n discrete reaches over the length of interest. Let $W(i)$ represent the length of reach i, $q_L(i)$ represent the average discharge per unit length through reach i, and $C_R(i)$ represent the average concentration ratio over reach i. From Equation (A2), $q_L(i)$ is given by the equation

$$q_L(i) = q_{DIL} * \frac{C_R(i)}{1 - C_R(i)} \quad \text{(A3)}$$

Let $\overline{q_L}$ represent the average value of q_L over the entire length of interest. This overall average is given by the equation

$$\overline{q_L} = \frac{\sum_{i=1}^{n} q_L(i) * W(i)}{\sum_{i=1}^{n} W(i)} \qquad \text{(A4)}$$

Let $q_R(i)$ represent $q_L(i)/\overline{q_L}$, the ratio of the average discharge per unit length over reach i to the average discharge per unit length over the entire length of interest. This ratio is termed the relative discharge. Substituting Equations (A3) and (A4) into the definition $q_R(i)$ for yields the following equation for relative discharge:

$$q_R(i) = \frac{\frac{C_R(i)}{1 - C_R(i)} * \sum_{i=1}^{n} W(i)}{\sum_{i=1}^{n} \frac{C_R(i) * W(i)}{1 - C_R(i)}} \qquad \text{(A5)}$$

Let $Q_P(i)$ represent the total discharge through reach i, expressed as a percentage of the total discharge over the entire length of interest. This quantity, termed the percent discharge, is given by

$$Q_P(i) = \frac{\frac{C_R(i)}{1 - C_R(i)} * W(i)}{\sum_{i=1}^{n} \frac{C_R(i) * W(i)}{1 - C_R(i)}} * 100\% \qquad \text{(A6)}$$

The relative discharge and the percent discharge are related as follows:

$$Q_P(i) = q_R(i) * \frac{W(i)}{\sum_{i=1}^{n} W(i)} * 100\% \qquad (A7)$$

It is important to note that the relative discharge is independent of reach length, while the percent discharge varies directly with reach length.

The procedure to compute the relative discharge and percent discharge for each reach is:

1) Compute the reach length, $W(i)$, and concentration ratio, $C_R(i)$, for each reach;

2) Compute the relative discharge, $q_R(i)$, for each reach using Equation (A5); and

3) Compute the percent discharge, $Q_P(i)$, for each reach using either Equation (A6) or Equation (A7).